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a division of
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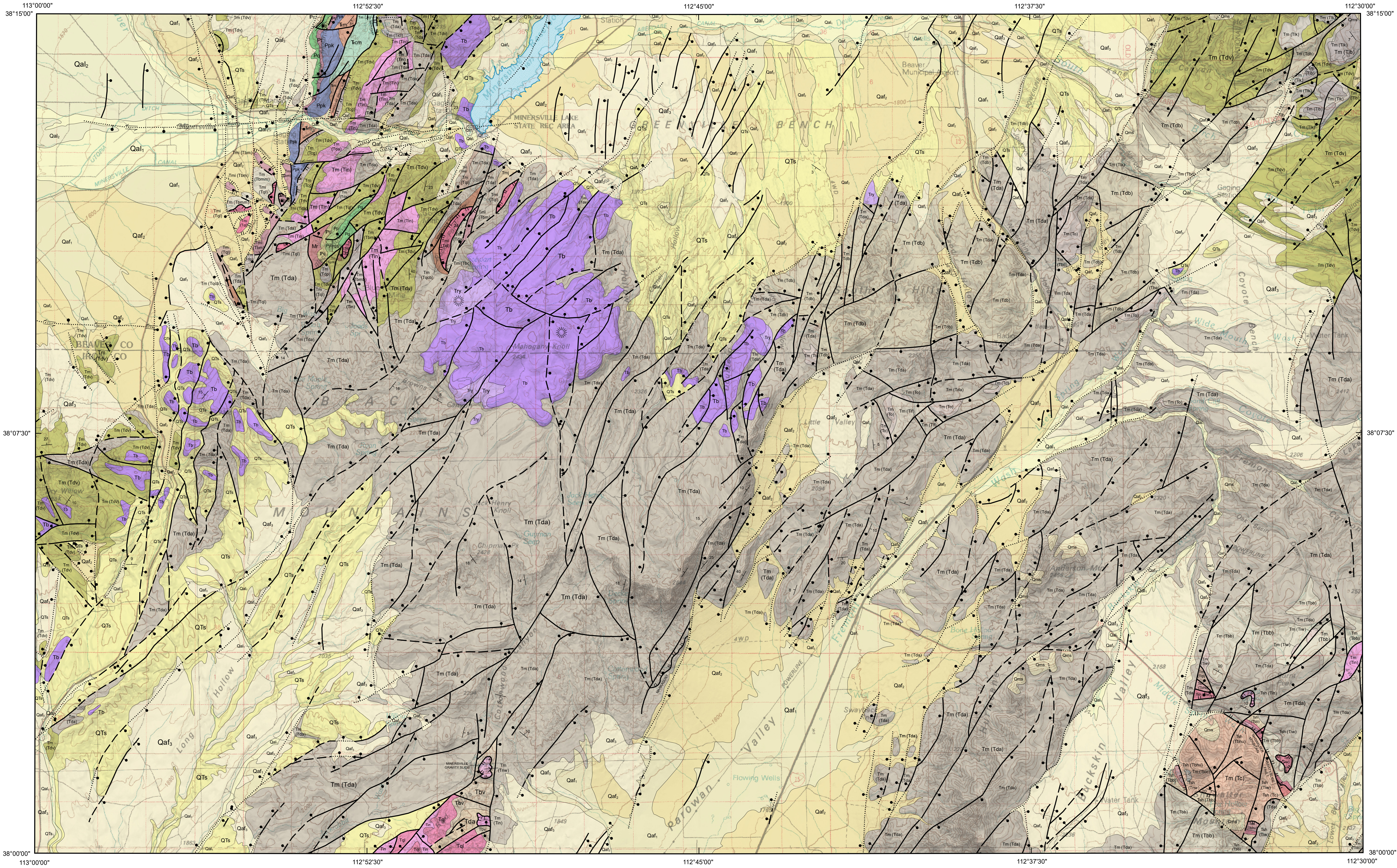

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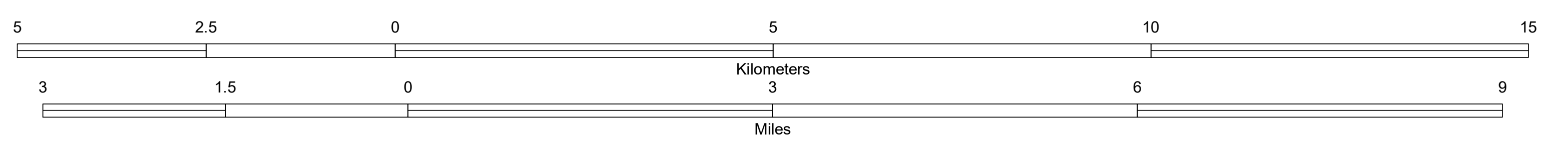
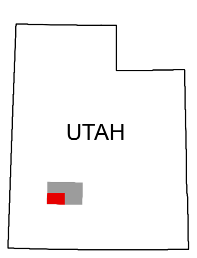
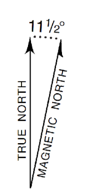


CONTOUR INTERVAL 40 METERS

SUPPLEMENTARY CONTOUR INTERVALS 10 METERS



MAP LOCATION



APPROXIMATE MEAN DECLINATION, 2018

INTERIM GEOLOGIC MAP OF THE SOUTHWESTERN QUARTER OF THE BEAVER 30' x 60' QUADRANGLE, BEAVER, IRON, AND GARFIELD COUNTIES, UTAH

by

Peter D. Rowley[1], Robert F. Biek[2], David B. Hacker[3], Garrett S. Vice[4], Robert E. McDonald[5], David J. Maxwell[6], Zachary D. Smith[6], Charles G. Cunningham[7], Thomas A. Steven[7], John J. Anderson[8], E. Bart Ekren[9], Michael N. Machette[10], and Bruce R. Wardlaw[7]

2018

[1]Geologic Mapping, Inc., New Harmony, Utah 84757
[2]Utah Geological Survey, Salt Lake City, Utah 84114
[3]Kent State University, Kent, Ohio 44242
[4]ExxonMobil Upstream Research Company, Houston, Texas 77060
[5]Pismo Beach, California 93448
[6]Dept. of Physical Science, Southern Utah University, Cedar City, Utah 84720
[7]U.S. Geological Survey, now deceased
[8]Seattle, Washington 98125
[9]White Sulphur Springs, Montana 59645
[10]Port Townsend, Washington 98368

RICHFIELD

Ranch Canyon	Bearskin Mountain	Gillies Hill	Pole Mountain	Mount Belknap	Mount Brigham	Marysvale	Marysvale Peak
Cave Canyon	Adamsville	Beaver	Black Ridge	Shelly Baldy Peak	Delano Peak	Piute Reservoir	Malmsten Peak
Minersville 3, 4	Minersville Reservoir 3, 4	Greenville Bench 2	Kane Canyon 2	Circleville Mtn	Circleville	Junction	Phonolite Hill
Dry Willow Peak 3, 4	Jack Henry Knoll 3, 4	Buckhorn Flat 1, 2	Burnt Peak 1, 2	Fremont Pass	Bull Rush Peak	Mount Dutton	Deep Creek

WAH WAH MOUNTAIN SOUTH (west); LOA (east)

PANGUITCH

SOUTHWESTERN QUARTER OF THE BEAVER 30' x 60' QUADRANGLE

INDEX OF 7.5-MINUTE QUADRANGLES AND SOURCES OF GEOLOGIC MAPPING

This geologic map was funded by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program through USGS STATEMAP Agreement Nos. 03HQAG0096 and 04HQAG0040.

Base from USGS Beaver 30' x 60' Quadrangle (1980)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1866

Project Manager: Grant C. Willis
GIS and Cartography: GIS Services & Consulting, LLC and Basia Matyjasik (UGS)

Utah Geological Survey
1594 West North Temple, Suite 3110
P.O. Box 146100, Salt Lake City, UT 84114-6100
(801) 537-3300
geology.utah.gov

This map was created from geographic information system (GIS) data

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Disclaimer

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OPEN-FILE REPORT 686DM
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
in cooperation with the
U.S. GEOLOGICAL SURVEY
2018

Blank pages are intentional for printing purposes.

DESCRIPTION OF GEOLOGIC UNITS

Where necessary, previously determined isotopic ages given here have been recalculated using the IUGS (International Union of Geological Sciences) decay constants (Steiger and Jager, 1977) and the tables of Dalrymple (1979).

QUATERNARY

Qf **Artificial-fill deposits** (Historical)—Man-made deposits of artificial fill for the dam at Minersville Reservoir.

Qal_1, Qal_2 **Alluvium** (Holocene and upper Pleistocene)—Sand, gravel, silt, and clay in channels, floodplains, and adjacent low terraces of major streams; subscript denotes relative age, with Qal_1 younger and Qal_2 older; maximum thickness about 30 feet (10 m).

Qat_1 **Younger stream-terrace deposits** (Holocene)—Sand and gravel that form dissected surfaces as much as 15 feet (5 m) above the level of adjacent modern streams; maximum thickness about 10 feet (3 m).

Qat_2 **Older stream-terrace deposits** (Holocene and upper Pleistocene)—Sand and gravel that form well dissected surfaces 15 to 40 feet (5–13 m) above the level of adjacent modern streams; maximum thickness about 10 feet (3 m).

Qaf_1 **Young alluvial-fan deposits** (Holocene)—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans and on coalesced alluvial fans and pediments (piedmont slopes); surface is young and generally undissected; thickness at least 30 feet (10 m).

Qaf_2, Qaf_3, Qaf_4

Middle alluvial-fan deposits (Holocene to middle Pleistocene)—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans and on coalesced alluvial fans and pediments (piedmont slopes); surfaces are moderately dissected by modern streams; subscript denotes relative age, with Qaf_2 youngest and Qaf_4 oldest; unit Qaf_4 is correlated with the gravel of Last Chance Bench in the Beaver basin (Machette and others, 1984); thickness at least 50 feet (15 m).

Qms **Landslide deposits** (Holocene and upper Pleistocene)—Unsorted, mostly angular, unstratified rock debris moved by gravity from nearby bedrock cliffs; maximum thickness about 100 feet (30 m).

QTs **Basin-fill sedimentary rocks** (lower Pleistocene to upper Miocene)—Poorly to moderately consolidated, tan and gray, tuffaceous sandstone and subordinate mudstone, siltstone, and conglomerate deposited in basins of different ages (late Pleistocene to late Miocene) and origins; basins were formed by normal faults and subordinate oblique and strike-slip faults of the episode of basin-range extension, whose beginning is poorly constrained but seems to be at about 20 Ma, if not older; basin-range extension reached maximum intensity and created the present topography largely after 10 Ma (e.g., Rowley and Dixon, 2001; Rowley and others, 2002; Biek and others, 2015a); deposits generally consist of fanglomerate near the present basin margins, piedmont slope deposits farther toward the centers of the basins, and lacustrine deposits near the centers of the basins; includes deposits studied in detail in the Beaver basin (Machette and others, 1984; Machette, 1985), which began to form at about 9 Ma (Evans and Steven, 1982); in the Kingston Canyon area east of the mapped area, the main phase of basin-range faulting is between about 7.6 and 5.4 Ma based on K-Ar ages published by Rowley and others (1981), and recently confirmed by new $^{40}Ar/^{39}Ar$ dating (Utah Geological Survey, unpublished data); thickness of overall map unit in the mapped area is variable but locally at least 2000 feet (600 m).

TERTIARY

Tb **Basalt lava flows** (Pliocene and upper Miocene)—Resistant, dark-gray and black, locally vesicular or amygdaloidal, crystal-poor (olivine and pyroxene phenocrysts), olivine basalt lava flows, flow breccia, and cinder cones; basaltic rocks and high-silica rhyolitic rocks make up an episode of bimodal magmatism that is synchronous with basin-range extension (Christiansen and Lipman, 1972; Rowley and Dixon, 2001; Biek and others, 2015a); in the southwest ¼ of the Beaver 30′ x 60′ quadrangle (Rowley and others, 2005), includes basalt in the Black Mountains that has a K-Ar age of 6.4 Ma (Best and others, 1980; Anderson and others, 1990a), and another north of it near

Minersville Reservoir that has a K-Ar age of 7.6 Ma; elsewhere in the Beaver quadrangle, basalt southeast of Otter Creek Reservoir east of the mapped area that has a K-Ar age of 5.0 Ma (Best and others, 1980), basalt in Kingston Canyon east of the mapped area that has a K-Ar age of 7.8 Ma (Rowley and others, 1981), basalt 2 miles (3 km) west of Piute Reservoir that has a K-Ar age of 10.9 Ma (Rowley and others, 1994a), and basalt east of Piute Reservoir that has K-Ar ages of 12.9 Ma (Damon, 1969) and 12.7 Ma (Best and others, 1980); maximum thickness of lava flows in the mapped area about 200 feet (60 m).

Try **Young rhyolite lava flows** (upper Miocene)—Small, resistant, mostly gray, flow-banded, crystal-poor, high-silica rhyolite volcanic domes and lava flows, and subordinate pyroclastic material; these rocks are part of the episode of bimodal magmatism and their eruptive centers help define an east-trending structural belt known as the Blue Ribbon transverse zone (Rowley and others, 1978; Rowley, 1998; Rowley and Dixon, 2001); this transverse zone includes east-striking faults that form the east-trending Black Mountains in and west of the mapped area (Rowley, 1978), as well as ranges east of the mapped area (Rowley and others, 2005) and extending west of the mapped area across the entire Great Basin (Rowley, 1998; Rowley and Dixon, 2001); in the Beaver 30′ x 60′ quadrangle (Rowley and others, 2005), the rhyolite bodies include the rhyolite of Phonolite Hill in Kingston Canyon east of the mapped area, which consists of several domes with K-Ar ages of 5.4 and 4.8 Ma (Rowley and others, 1981); a dome at Blue Ribbon Summit in the Black Mountains that has a K-Ar age of 7.6 Ma (Mehnert and others, 1978; Rowley and others, 1978); a dome at Teddys Valley in the Black Mountains that has a K-Ar age of 7.9 Ma (Anderson and others, 1990a); and a dome southwest of Beaver in the Black Mountains that has a K-Ar age of 8.3 Ma (Anderson and others, 1990a); also includes a small dome in Corral Canyon, west of the Mineral Mountains and north of the mapped area, that has a K-Ar age of 7.9 Ma (Lipman and others, 1978; see also Evans and Steven, 1982); in most places the maximum thickness of the rhyolites is less than 200 feet (60 m).

Tmj **Joe Lott Tuff Member of the Mount Belknap Volcanics** (lower Miocene)—Moderately resistant, light-gray and tan, partly welded, crystal-poor, high-silica rhyolite ash-flow tuff, with a black basal vitrophyre; the main outflow unit that is derived from the Mount Belknap caldera (Cunningham and Steven, 1979) is well exposed as several thick cooling units in lower Clear Creek Canyon 24 miles (39 km) northeast of the mapped area (Budding and others, 1987; Rowley and others, 2002; Hintze and others, 2003); rocks of the Mount Belknap Volcanics and their source plutons in the Mount Belknap caldera and the Central mining area near Marysvale are part of the bimodal magmatic episode and contain ore deposits of lithophile elements such as uranium, alunite, and molybdenum in the Beaver and Richfield 30′ x 60′ quadrangles (Kerr and others, 1957; Callaghan, 1973; Steven and others, 1981; Cunningham and others, 1982, 1984a, 1998a,b, 2005, 2007; Rowley and others, 1988a,b, 2005; Hintze and others, 2003); K-Ar ages on overlying and underlying units indicate an age of the map unit of 19 Ma (Steven and others, 1979), and this interpretation is confirmed by a new $^{40}Ar/^{39}Ar$ age on sanidine of 19.12 ± 0.10 Ma (Utah Geological Survey, unpublished data); as such, this unit is one of the oldest known units that postdates emplacement of the Markagunt gravity slide, as discussed below; maximum thickness about 400 feet (120 m).

Markagunt Megabreccia (lower Miocene)—Deformed pre-existing rocks, including breccia, huge mountain-sized blocks (megabreccia), cataclasite, and rare pseudotachylyte, and large masses and areas of transported yet seemingly intact rock; these rocks make up the Markagunt gravity slide, the world's largest known subaerial slide mass, with an aerial extent of at least 2000 square miles (5000 km^2), about the size of the state of Delaware (Biek and others, 2014; Hacker and others, 2014, 2015). The slide underlies the entire map area and represents failure of the southwestern side of the Marysvale volcanic field, which catastrophically moved southward across areas that later, after basin-range tectonism, became the southern Tushar Mountains, southern Mineral Mountains, Black Mountains, Red Hills, northern and central Markagunt Plateau, and valleys in between. As such, the Markagunt slide is larger than the Heart Mountain gravity slide in northwestern Wyoming, at 1300 square miles (3400 km^2) in areal extent, formerly considered the largest subaerial slide (e.g., Malone and Craddock, 2008; Craddock and others, 2009, 2012; reinterpretation of enigmatic volcanic rocks at Squaw Peaks led Malone and others [2014] to suggest that the Heart Mountain slide may be larger still, also at least 5000 km^2). The Markagunt gravity slide was discovered in the mid-1970s during thesis geologic mapping in the northern and central Markagunt Plateau by graduate students of John J. Anderson, then Professor at Kent State University. We use the name Markagunt Megabreccia, as proposed by Anderson (1993) with a type section along Panguitch Creek southwest of the town of Panguitch, for the deposits of the Markagunt gravity slide. Although the gravity slide was not recognized to extend as far north as the area of the Beaver 30′ x 60′ quadrangle during our initial mapping (e.g., Rowley and others, 2005), we now know that it underlies most of the Beaver quadrangle, including most of the Tushar Mountains, Mineral Mountains, and Black Mountains, and extends not only south of the quadrangle (Biek and others, 2015a) but locally north, west, and southwest of the quadrangle. Curiously, another huge gravity slide, called the

Sevier gravity slide, was discovered by coauthors Biek and Hacker in 2016 in the Sevier Plateau east of the Beaver SW mapped area and represents southward failure of the southeastern flank of the Marysvale field several million years earlier than the Markagunt slide; the Sevier gravity slide is now being mapped not only in the eastern Beaver 30′ x 60′ quadrangle but also east (Biek and others, 2015b) and south of the quadrangle.

The rocks of both slides are predominantly Miocene and Oligocene calc-alkaline (which range in chemistry from andesite to low-silica rhyolite and therefore predate bimodal magmatism) volcanic rocks that erupted in the Marysvale volcanic field as well as calc-alkaline ash-flow tuffs that erupted from calderas in the Great Basin to the west and intertongued with Marysvale rocks (e.g., Lipman and others, 1972). The primary failure plane of both slides was mostly in incompetent tuffaceous sedimentary rocks of the Brian Head Formation, which immediately underlies the volcanic rocks. The failure plane for the Markagunt slide, located beneath the southern Tushar Mountains, Mineral Mountains, and Black Mountains, rose to the surface as a ramp in the northern Markagunt Plateau and Red Hills; south of the ramp, the slide mass moved along the Miocene land surface for about 20 miles (30 km) (Biek and others, 2015a). The modern erosional southern edge of the Markagunt slide is on the southern side of Haycock Mountain, southeast of Panguitch Lake (Biek and others, 2015a). In one part of the Markagunt slide, in the southern Mineral Mountains at the northern edge of the mapped area but mostly just north of the mapped area, a lower failure plane is exposed within incompetent shales of the Petrified Forest Member of the Upper Triassic Chinle Formation, cutting out nearly 1000 feet (300 m) of Lower Jurassic strata. There, the slide carries Navajo Sandstone and younger rocks and is shown by a different symbol on the map.

In addition to the Markagunt gravity slide, the mapped area contains two small gravity slides, the Minersville gravity slide and the Showalter Mountain gravity slide, that appear to be slightly older than the Markagunt slide and therefore were carried along by the younger Markagunt slide. Therefore, in the mapped area, all exposed rocks except those older than the Petrified Forest Member and presumably some plutons, and rocks younger than about 21 Ma, have been transported generally southward within the Markagunt slide.

The Harmony Hills Tuff is the youngest known rock unit below the Markagunt slide and involved in the slide in the western Black Mountains west of the mapped area. This tuff is derived from the Bull Valley Mountains in the Great Basin (Williams, 1967; Rowley and others, 1995). The Harmony Hills Tuff has a $^{40}Ar/^{39}Ar$ age of 22.03 ± 0.15 Ma (Cornell and others, 2001). The oldest known rock unit that overlies the slide is the Haycock Mountain Tuff, exposed in the Panguitch Lake area (Anderson, 1993), with a U-Pb age on zircon of 21.6 ± 0.73 Ma (Biek and others, 2015a). We interpret that failure of the Markagunt slide took place rapidly sometime between 22 and 21 Ma. As with the Sevier, Minersville, and Showalter Mountain slides, the Markagunt slide took place during calc-alkaline magmatism.

The map units involved in the gravity slide are in many places not deformed or little deformed, so they may be correlated easily with named rock units not involved in the slide or, where not badly deformed, were mapped and named before recognition of the slide (e.g., Cunningham and others, 1983; Rowley and others, 2002, 2005). Therefore, following the usage of Biek and others (2015a), the deformed rocks have been designated with a symbol consisting of a prefix "Tm," followed in parentheses by the symbol for the named undeformed rock unit (e.g., Tm [Tda]). These components of the slide are listed below; for their descriptions, see the named pre-existing (undeformed) rock unit, given elsewhere in the text and in the correlation chart in its proper stratigraphic position. The units in the Minersville (prefix Tmi) and Showalter Mountain (prefix Tsh) slides are similarly described. However, even though these slides were remobilized in the younger Markagunt slide, to avoid an overly long unit label, we do not show the Markagunt prefix on the map; for example, we show Tmi (Tql), but not Tm (Tmi [Tql]).

Tm (Tbmb) **Markagunt Megabreccia, Conglomerate of Big Wash component**

Tm (Tbmm) **Markagunt Megabreccia, Conglomerate of Muddy Hill component**

Tm (Ticc) **Markagunt Megabreccia, Concordant intrusions component**

Tm (Ticl) **Markagunt Megabreccia, Lincoln Stock component**

Tm (Tdv) **Markagunt Megabreccia, Mount Dutton Formation, vent facies component**

Tm (Tda) **Markagunt Megabreccia, Mount Dutton Formation, alluvial facies component**

Tm (Tdb) **Markagunt Megabreccia, Mount Dutton Formation, Beaver Member component**

Tm (Tdp) **Markagunt Megabreccia, Mount Dutton Formation, Plugs and dikes component**

Tm (Tqcb) **Markagunt Megabreccia, Bauers Tuff Member of the Condor Canyon Formation component**

Tm (Tql) **Markagunt Megabreccia, Leach Canyon Formation component**

Tm (Tlf) **Markagunt Megabreccia, Tuff of Lion Flat component**

Tm (To) **Markagunt Megabreccia, Osiris Tuff outflow facies component**

Tm (Tlb) **Markagunt Megabreccia, Mafic lava flows of Birch Creek Mountain component**

Tm (Tbc) **Markagunt Megabreccia, Bullion Canyon Volcanics component**

Tm (Tbv) **Markagunt Megabreccia, Bear Valley Formation component**

Tm (Tlk) **Markagunt Megabreccia, Lava flows of Kents Lake component**

Tm (Tbb) **Markagunt Megabreccia, Buckskin Breccia component**

Tm (Tin) **Markagunt Megabreccia, Isom Formation and the Needles Range Group component**

Tm (Tiw) **Markagunt Megabreccia, Isom Formation and the Wah Wah Springs Formation component**

Tm (Tnw) **Markagunt Megabreccia, Wah Wah Springs Formation component**

Tm (Tbhu) **Markagunt Megabreccia, Brian Head Formation, upper volcanic unit component**

Tm (Tcg) **Markagunt Megabreccia, Conglomerate component**

Tm (Tc) **Markagunt Megabreccia, Claron Formation component**

Tm (Jn) **Markagunt Megabreccia, Navajo Sandstone component**

Ticc **Concordant intrusions** (lower Miocene to lower Oligocene)—Resistant, gray monzonite (calc-alkaline) intrusions in the Markagunt Plateau (Anderson, 1965; Anderson and Rowley, 1975; Anderson and others, 1990a, b); demonstrably or probably all laccoliths that intrude into the Claron (Tc) or Brian Head (Tbh) Formations; includes the pluton of Showalter Mountain (Anderson and others, 1990a), which caused the Showalter Mountain gravity slide and which has an $^{40}Ar/^{39}Ar$ age on hornblende of 26.24 ± 0.02 Ma (UGS unpublished data); one such pluton, the Spry Intrusion in Circleville Canyon just east of the mapped area (Anderson and others, 1990b; Rowley and others, 2005), is of batholith size in outcrop (Grant and Anderson, 1979) and extends well to the south in the subsurface (Blank and Kucks, 1989; Bankey and others, 1998); the Spry intrusion has an age of about 26 to 25 Ma (Anderson and others, 1990b; Utah Geological Survey, unpublished data) and it erupted the Buckskin Breccia (Tbb).

Ticl **Lincoln Stock** (lower Miocene)—Resistant, light-gray monzonite and granodiorite porphyry stock in the southern Mineral Mountains (Earll, 1957; Corbett, 1984; Price, 1998), resulting in contact metamorphic lead-zinc-gold ore deposits of the Lincoln and Bradshaw mining districts just north of the mapped area; pluton is interpreted here to represent a calc-alkaline phase of the Mineral Mountains batholith, also to the north; the stock itself is just north of the mapped area, but two dikes thought to be related to the main stock are present in the mapped area; stock has a K-Ar age of 21.9 Ma (Bowers, 1978) and a preliminary U-Pb zircon age of about 23 Ma (Coleman and others, 1997, 2001), and one of the dikes has K-Ar ages of 22.5 ± 0.9 (biotite) and 22.3 ± 0.8 Ma (sanidine) (Rowley and others, 1994a).

Deposits from unroofing of Black Mountain (lower Miocene)

Tbmb **Conglomerate of Big Wash**—Resistant, tan, pink, and gray, silicified, pebble and boulder fluvial conglomerate and coarse sandstone made up of rounded clasts, in a northern tributary to Big Wash on the eastern side of Black Mountain, which is southeast of Minersville; the clasts were derived as fan alluvium from unroofing by streams of the Black Mountain area following rapid uplift that was interpreted by Rowley and others (2014) to be due to emplacement of an underlying blind calc-alkaline pluton, perhaps a laccolith; clasts are of pink Queantoweap Sandstone (Pq), white chert and minor light-gray carbonate probably from other Permian rocks, and purple lava flows of the Mount Dutton Formation (Black Mountain flow member) that were derived from a stratovolcano whose remains underlie southern Black Mountain; the conglomerate includes in its upper part the Black Mountain tuff member of the Mount Dutton Formation, a red crystal-poor dacitic ash-flow tuff at least 10 feet (3 m) thick that was interpreted to have been erupted from the blind pluton; the map unit largely postdates the Minersville gravity slide (Rowley and others, 2014); thickness at least 100 feet (30 m), with the base not exposed.

Rocks of the Minersville gravity slide—Deformed pre-existing rocks, including breccia, cataclasite, and rare pseudotachylyte, of the Minersville gravity slide, a small slide centered on northern Black Mountain, about 2 miles (3 km) southeast of Minersville (Rowley and others, 2014, plate 1); northern Black Mountain is a horst block of Permian to Mississippian rocks that is surrounded by Tertiary volcanic rocks and must have been uplifted many thousands of feet; uplift was interpreted to be due to rapid emplacement of a blind pluton, perhaps a laccolith, that fed an overlying stratovolcano, the intrusive andesitic feeder plug (Tdb) that underlies southern Black Mountain; the slide mass consists entirely of light-tan and pink, brecciated and silicified ash-flow tuff of the Leach Canyon Formation (Tql, 23.8 Ma; see description below) that was spread at least 3 miles (5 km) radially from Black Mountain; the slide was locally emplaced onto the Bauers Tuff Member of the Condor Canyon Formation (Tqcb, see description below), which has $^{40}Ar/^{39}Ar$ ages of 22.8 Ma, so the slide postdates that age; a local dacitic ash-flow tuff (Black Mountain tuff member of the Mount Dutton Formation), exposed on the eastern side of Black Mountain (interbedded with the conglomerate of Big Wash) and interpreted to have vented from the blind pluton, indicates that the pluton was calc-alkaline and therefore predates basin-range tectonism, which began at about 20 Ma; the Minersville gravity slide and its overlying conglomerate of Big Wash (Tbmb) and its underlying conglomerate of Muddy Hill (Tbmm) were in turn incorporated in the giant south-moving Markagunt gravity slide; thickness of the Minersville slide mass about 100 feet (30 m).

Tmi (Tql) **Rocks of the Minersville gravity slide, Leach Canyon Formation component**

Tmi (Tbm) **Rocks of the Minersville gravity slide, Leach Canyon Formation and conglomerate of Muddy Hill component—**Units combined where map scale does not permit separating them, yet only the Leach Canyon Formation slid as the Minersville gravity slide.

Tbmm **Conglomerate of Muddy Hill**—Resistant dark-reddish-brown, sandy conglomerate and sandstone made up of well-rounded clasts and subrounded boulders of volcanic rocks, mostly of the Black Mountain flow member and its feeder plug of Black Mountain, but also some clasts from the Leach Canyon Formation; exposed on Muddy Hill and other hills west of Black Mountain and south of Minersville; unit underlies the Minersville gravity slide and is interpreted to be fan alluvium that was deposited during the initial unroofing of Black Mountain when the Tertiary volcanic rocks were stripped off Paleozoic rocks as the local area was uplifted rapidly during emplacement of an inferred blind pluton beneath Black Mountain, after which slope failure led to the Minersville gravity slide (Rowley and others, 2014); thickness at least 250 feet (75 m), with the base not exposed.

Mount Dutton Formation (lower Miocene to lower Oligocene)—Resistant to non-resistant, brown, tan, pink, and gray, volcanic mudflow breccia made up mostly of matrix-supported angular clasts as well as resistant lava flows and flow breccia; the clasts in the mudflow breccia and the lava flows are of crystal-poor, generally pyroxene-bearing, andesitic rock of the same lithology; unit also includes minor fluvial and eolian sandstone and conglomerate whose clasts are the same lithology (Anderson and Rowley, 1975); deposited from clustered stratovolcanoes that form most of the southern Marysvale volcanic field (e.g., Callaghan, 1939; Anderson and Rowley, 1975; Rowley and others, 1979, 1998, 2002; Steven and others, 1979, 1990; Cunningham and others, 1983; Campbell and others, 1999); K-Ar dated at 26 to 21 Ma (Fleck and others, 1975) but some deposits predate the Wah Wah Springs Formation (Tnw) and therefore are 30 Ma or older; the most voluminous unit in the Marysvale volcanic field; thickness in the area at least 6000 feet (2000 m).

Tdv **Vent facies**—Lava flows, volcanic mudflow breccia, and flow breccia interpreted to represent near-source eruptions (Anderson and Rowley, 1975); many of the source stratovolcanoes are aligned east-west along the east-striking Blue Ribbon transverse zone (Rowley and others, 1978, 1998; Rowley, 1998), which passes across the Beaver 30′ x 60′ quadrangle west from Kingston Canyon along the break in slope between the Tushar Mountains and Markagunt Plateau, then along the northern side of the Black Mountains and on to the west.

Tda **Alluvial facies**—Primarily volcanic mudflow breccia in which lithologies are more heterogeneous than in the vent facies, representing deposits interpreted to have traveled farther from the source, down the flank of individual stratovolcanoes (Anderson and Rowley, 1975), passing into conglomerate still farther from the source; the unit is by far the most voluminous component of the formation.

Tdb **Beaver Member**—Resistant, gray, pink, tan, green, and reddish-brown, dense, thick-bedded, crystal-rich, andesite porphyry lava flows and flow breccia of several volcanic domes, and local tuffaceous sandstone, volcanic mudflow breccia, and tuff (Anderson and Rowley, 1975); corrected K-Ar ages of 26.2 ± 0.8 and 25.0 ± 0.5 Ma (Fleck and others, 1975); exposed only south of Beaver; maximum thickness about 600 feet (200 m).

Tdp **Plugs and dikes**—Small source calc-alkaline magma bodies (vents) of the formation (e.g., Blackman, 1985); the crystal-poor (poorly differentiated) nature of the rock, coupled with the low volume of its source plutons, suggest that the intrusive sources of the volcanic rocks of the formation are deep.

Quichapa Group (lower Miocene and upper Oligocene) —Defined by Mackin (1960) and Williams (1967) for a series of regional ash-flow tuffs derived from the Great Basin; two of these are exposed in the study area; the youngest tuff of the Quichapa Group is the Harmony Hills Tuff, which is not exposed in the study area, but is important because it is the youngest unit overlain by and involved in the Markagunt gravity slide; it is exposed in the Panguitch 30′ x 60′ quadrangle (Biek and others, 2015a) just south of the Beaver quadrangle and in the Thermo 15′ quadrangle (Rowley, 1978) about 5 miles (8 km) west of the Beaver quadrangle; the age of the Harmony Hills Tuff is 22.03 ± 0.15 Ma (Cornell and others, 2001) by $^{40}Ar/^{39}Ar$ analysis.

Tqcb **Bauers Tuff Member of the Condor Canyon Formation** (lower Miocene)—Resistant brown and light-purple, crystal-poor, densely welded, dacitic to trachydacitic ash-flow tuff; derived from the southwestern part (Clover Creek caldera, in Nevada) of the Caliente caldera complex, which spans the Utah-Nevada border (Rowley and others, 1992, 1994b, 1995); age is 22.8 Ma based on $^{40}Ar/^{39}Ar$ ages, one an average of 22.78 Ma on samples of the member (Best and others, 1989b, Table R3) and another a plateau age on sanidine of 22.8 ± 0.1 Ma by L.W. Snee on the intracaldera pluton of the Clover Creek caldera of the Caliente caldera complex just north of Caliente, Nevada (Rowley and others, 1994b); map unit is exposed on Black Mountain north of the plug of southern Black Mountain (mapped as Tdp); thickness about 70 feet (20 m).

Tql **Leach Canyon Formation** (upper Oligocene)—Moderately resistant, tan and gray, crystal-poor, poorly welded, low-silica rhyolite ash-flow tuff; source probably the Caliente caldera complex of eastern Nevada, as suggested by isopachs (Williams, 1967; Rowley and others, 1995); an apparent $^{40}Ar/^{39}Ar$ age of about 23.8 Ma (Best and others, 1993) based on oral communication with Professor Myron Best (Brigham Young University), as discussed by Rowley and others (1994a); maximum thickness about 150 feet (50 m), thickening southwestward.

Tlf **Tuff of Lion Flat** (lower Miocene)—Soft, pink, white, tan, and gray, unwelded, crystal-poor, rhyolite ash-flow tuff and minor airfall and water-laid tuff (Wickstrom, 1982; Lanigan and Anderson, 1987); probably tuff-ring deposits related to eruption of the volcanic rocks of Lousy Jim (Sigmund, 1979), exposed overlying the tuff of Lion Flat just north of the mapped area (Rowley and others, 2002); the volcanic rocks of Lousy Jim yielded a new $^{40}Ar/^{39}Ar$ age on sanidine of 22.88 ± 0.02 Ma (Utah Geological Survey, unpublished data); maximum thickness about 300 feet (100 m).

To **Osiris Tuff, outflow facies** (lower Miocene to upper Oligocene)—Resistant, light-gray (upper vapor phase zone) and brown (lower part), densely welded, moderately crystal-rich, rhyodacitic ash-flow tuff with prominent euhedral biotite phenocrysts (Williams and Hackman, 1971); one or two cooling units containing black basal vitrophyres; contains drawn-out pumiceous lenticules; upper part locally contains steeply-dipping flow-foliated rock caused by secondary flowage of rock fused in the last few tens of meters of movement; derived from the Monroe Peak caldera, the largest in the Marysvale volcanic field (Steven and others, 1984b; Rowley and others, 1986a, b) and just northeast of the mapped area; K-Ar age is about 23 Ma (Fleck and others, 1975; Cunningham and others, 2007; Ball and others, 2009); maximum thickness about 200 feet (60 m).

Tlb **Mafic lava flows of Birch Creek Mountain** (lower Miocene and upper Oligocene)—Moderately resistant, dark-gray to black, vesicular to dense lava flows of olivine-bearing basaltic andesite or trachybasalt exposed in and near Birch Creek Mountain in the southeastern Tushar Mountains (Wickstrom, 1982; Anderson and others, 1990a, b); contains generally anhedral phenocrysts of olivine (generally altered to iddingsite), augite, and plagioclase generally less than 1 mm long in a groundmass generally of devitrified glass consisting of microlites of plagioclase, augite, and Fe-Ti oxides; perhaps correlative with an early eruptive sequence of the potassium-rich mafic lava flows that are exposed just east and northeast of the mapped area; map unit appears to be a source of the mafic gravels of Gunsight Flat, exposed just east of the mapped area and interpreted to have been deposited in basins created by north-dipping (antithetic) faults of the Markagunt gravity slide; corrected K-Ar ages from samples of two flows are 22.9 ± 0.4 and 22.4 ± 0.4 Ma ("older basalts" of Fleck and others, 1975), but these are supplanted by a new $^{40}Ar/^{39}Ar$ age of 23.51 ± 0.06 Ma on a groundmass concentrate (Utah Geological Survey, unpublished data); thickness typically 200 feet (60 m) to as much as 500 feet (150 m).

Tbc **Bullion Canyon Volcanics** (lower Miocene to lower Oligocene)—Moderately resistant, tan, gray, pink, and light-green lava flows, flow breccia, volcanic mudflow breccia, and minor ash-flow tuff and fluvial conglomerate and sandstone (Callaghan, 1939; Rowley and others, 1979; Steven and others, 1979; Cunningham and others, 1984b, 1994, 1998b, 2007; Rowley and others, 2002); the product of clustered stratovolcanoes, made up of undivided vent-facies and alluvial-facies rocks; the second-most voluminous stratigraphic unit in the Marysvale volcanic field; mostly crystal-rich dacite, thus more highly evolved than the Mount Dutton Formation, with which it intertongues; unit derived from intrusive sources that are abundantly exposed elsewhere in the Beaver 30′ x 60′ quadrangle (Rowley and others, 2005) and are much more shallow than those for the Mount Dutton Formation; isotopic dates and stratigraphic relationships indicate an age of at least 30 to 22 Ma (Steven and others, 1979; Kowallis and Best, 1990; Rowley and others, 1994a); rocks of the unit and its source plutons have high potential for mineral resources of the chalcophile elements (Callaghan, 1973; Steven and others, 1979; Cunningham and others, 1984b, 1994, 1998b, 2007; Steven and Morris, 1987); thickness at least 5000 feet (1500 m).

Tbv **Bear Valley Formation** (upper Oligocene)—Generally soft, characteristically light-green but locally gray and yellow, moderately to well sorted, commonly cross-bedded, fine- to medium-grained, tuffaceous sandstone of mostly eolian but locally fluvial origin, interbedded volcanic mudflow breccia, airfall tuff, and poorly and highly welded ash-flow tuff (Anderson, 1971); has K-Ar ages of about 25 Ma (Fleck and others, 1975); maximum thickness about 1000 feet (300 m).

Tlk **Lava flows of Kents Lake** (upper Oligocene)—Moderately resistant, light- to medium-gray, dense, medium- to thick-bedded, andesite porphyry lava flows exposed on the crest of the southern Tushar Mountains (Anderson and others, 1990a, b), some of which were mismapped as the Osiris Tuff; flows contain 20–40 percent phenocrysts of plagioclase (1–10 mm but typically 2–4 mm long), subordinate amounts of pyroxene (0.1–3 mm but typically 0.5 mm long), and minor amounts of Fe-Ti oxides, amphibole, and biotite in a partly devitrified glassy groundmass containing aligned microlites, chiefly plagioclase; distinguished from the vent phase (Tdv) of the Mount Dutton Formation by the presence of biotite and from the Beaver Member (Tdb) of the Mount Dutton Formation by the absence of quartz; some flows contain a dark-gray basal glass; flows contain pronounced sub-horizontal platy parting that reflects primary flow lamination; may include one ash-flow tuff containing the same mineral assemblage in a densely welded glass groundmass; yielded a new $^{40}Ar/^{39}Ar$ age of 25.36 ± 0.41 Ma on plagioclase (Utah Geological Survey, unpublished data); thickness generally 130 to 260 feet (40–80 m), with a maximum of about 800 feet (250 m).

Tbb **Buckskin Breccia** (upper Oligocene)—Moderately resistant, gray and pink, poorly to moderately welded, crystal-poor, dacitic ash-flow tuff, flow breccia, volcanic mudflow breccia, conglomerate, and sandstone (Anderson and Rowley, 1975; Yannacci, 1986); characterized by as much as 50 percent rock volume of distinctive crystal-rich lithic clasts identical to rock of the Spry Intrusion, from which the unit was derived just east of the mapped area; locally intertongues with the Isom Formation (Tin) and considered to have an age of about 26 Ma based on K-Ar ages of the intrusion and related volcanic rocks (Anderson and others, 1990b; Rowley and others, 1994a) and a new U-Pb age on zircon of 26.30 ± 0.28 Ma on the Spry intrusion (Utah Geological Survey, unpublished data); maximum thickness about 250 feet (80 m).

Rocks of the Showalter Mountain gravity slide (upper Oligocene)—Deformed pre-existing rocks of the Showalter Mountain gravity slide, a small gravity slide that is confined to the flanks of a laccolith between Buckskin Valley and Bear Valley in the northern Markagunt Plateau (Anderson, 1965; Anderson and others, 1990a); only a small part of the inferred laccolith (Ticc) is exposed where it intrudes the Claron Formation (Tc), whose rocks failed during rapid intrusion and uplift of the laccolith; age is that of the laccolith (unit Ticc, 26.24 ± 0.02 Ma) and after deposition of the youngest known unit involved in the slide, the Buckskin Breccia (Utah Geological Survey, unpublished data); road cuts where State Highway 20 cuts through the northern flank of the laccolith spectacularly display slide breccia; the area later was deformed by movement of the Markagunt gravity slide.

Tsh (Tbb) **Rocks of the Showalter Mountain gravity slide, Buckskin Breccia component**

Tsh (Tin) **Rocks of the Showalter Mountain gravity slide, Isom Formation and Needles Range Group component**

Tsh (Tnw) **Rocks of the Showalter Mountain gravity slide, Wah Wah Springs Formation component**

Tsh (Tiw) **Rocks of the Showalter Mountain gravity slide, Isom Formation and the Wah Wah Springs Formation component**

Tsh (Tbhu) **Rocks of the Showalter Mountain gravity slide, Brian Head Formation, upper volcanic unit component**

Tsh (Tc) **Rocks of the Showalter Mountain gravity slide, Claron Formation component**

Isom Formation and Needles Range Group

Tiw **Isom Formation and Wah Wah Springs Formation of the Needles Range Group, undivided** (upper and lower Oligocene)

Isom Formation (upper Oligocene)—Resistant, brown and reddish-brown, crystal-poor, densely welded, trachydacitic ash-flow tuff (Mackin, 1960; Fryman, 1987) derived apparently from the Indian Peak caldera complex at the Utah-Nevada border (Best and others, 1989a, b); age about 27–26 Ma on the basis of many $^{40}Ar/^{39}Ar$ and K-Ar ages (Best and others, 1989b; Rowley and others, 1994a); exposed in the Black Mountains and western parts of the Markagunt Plateau; maximum thickness about 30 feet (10 m).

Tnw **Wah Wah Springs Formation** (lower Oligocene)—Resistant, gray, tan, pink, and light-purple, crystal-rich, moderately welded, dacite ash-flow tuff (Mackin, 1960) derived from the Indian Peak caldera complex (Best and others, 1989a, b); exposed in the Markagunt and Sevier Plateaus; many isotopic ages establish it as 30.5 Ma (Best and others, 1989a); thickness about 50 feet (15 m).

Tin **Isom Formation and the Needles Range Group, undivided** (upper and lower Oligocene) (includes Isom Formation, described above).

Needles Range Group (lower Oligocene)—Resistant, gray, tan, pink, medium-red, and light-purple, crystal-rich, moderately welded, dacite ash-flow tuff (Mackin, 1960) derived from the Indian Peak caldera complex (Best and others, 1989a, b); exposed in the Minersville area, where it consists of both the Lund Formation (27.9 Ma; Best and others, 1989a) and the Wah Wah Springs Formation; maximum thickness about 100 feet (30 m).

Brian Head Formation (lower Oligocene to middle Eocene)—Volcanic rocks that can be demonstrated to predate the Wah Wah Springs Formation, and underlying, mostly light-gray, soft, tuffaceous fluvial and lacustrine sedimentary rocks; well studied in the Brian Head area, where the unit names were proposed (Sable and Maldonado, 1997; Biek and others, 2015a).

Tbhu **Upper volcanic unit**—Heterogeneous assemblage of mostly resistant lava flows, ash-flow tuff, flow breccia, volcanic mudflow breccia, and tuffaceous sandstone that predates the Wah Wah Springs Formation (Anderson and Rowley, 1975; Biek and others, 2015a); a corrected K-Ar age of 31.9 Ma was determined on an ash-flow tuff (Fleck and others, 1975); maximum thickness about 450 feet (140 m).

Tcg **Conglomerate** (Eocene and/or Paleocene)—Moderately resistant, white, tan, and light-gray, fluvial conglomerate and sandstone characterized by pebbles of quartzite and carbonates as much as 3 feet (1 m) in diameter, resting unconformably on Mesozoic sedimentary rocks and conformably overlain by Tertiary volcanic rocks; where exposed in the southern Mineral Mountains and Minersville area, its maximum thickness is about 120 feet (40 m); these beds contain the main shear plane of the Markagunt gravity slide in the southern Mineral Mountains and northern Black Mountains; exposed also as a patch that includes tuffaceous sandstone as much as 30 feet thick (10 m) in the central Tushar Mountains east of the mapped area.

Tc **Claron Formation** (Eocene and Paleocene)—Soft to resistant, white and gray upper part of mostly lacustrine limestone and red lower part of fluvial sandstone, siltstone, mudstone, and conglomerate; fluvial strata commonly exhibit well-developed paleosols; distinguished from the Brian Head Formation in not containing volcanic material; maximum thickness several hundred feet (100 m), but much thicker to the south (Biek and others, 2015a).

JURASSIC

Jn **Navajo Sandstone** (Lower Jurassic)—Resistant, red, yellow, and gray, locally spectacularly cross-bedded, fine- to medium-grained, eolian sandstone (Earll, 1957; Price, 1998); exposed northeast of Minersville, especially north of the mapped area and east of the mapped area in the central Tushar Mountains; maximum exposed thickness about 1500 feet (450 m) northeast of Minersville and 2000 feet (600 m) in the central Tushar Mountains.

TRIASSIC

Ꞧcm **Chinle Formation and Moenkopi Formation, undivided**

Chinle Formation (Upper Triassic)—Fluvial and lacustrine rocks of the upper Petrified Forest Member and the underlying Shinarump Conglomerate Member; the Petrified Forest Member is soft to moderately resistant, red, maroon, brown, tan, and white mudstone, and a basal bed of purple, coarse-grained sandstone; the member is incompetent and prone to landsliding over most of its area of distribution in Utah, Nevada, and Arizona; the Shinarump Conglomerate Member is moderately resistant, red to brownish-red, fine- to medium-grained conglomerate; the entire Chinle Formation is exposed only in the central Tushar Mountains east and northeast of the mapped area, where the combined thickness is about 600 feet (200 m); north of Minersville and mostly north of the mapped area, the Petrified Forest Member has been removed by faulting along the lowest known fault of the Markagunt gravity slide, and the Shinarump Member below the fault has a maximum thickness of 20 feet (6 m).

Ꞧm **Moenkopi Formation** (Lower Triassic)—Soft and locally resistant, red, brown, pink, light- and dark-gray, and greenish-gray, marine and continental, thin-bedded siltstone, shale, and subordinate locally fossiliferous limestone (Earll, 1957; Price, 1998); exposed east and northeast of Minersville and in the central Tushar Mountains; thickness about 1300 feet (400 m) to 1700 feet (500 m).

PERMIAN

Ppk **Plympton and Kaibab Formations, undivided**—Mapped only east and north of Minersville.

Plympton Formation—Moderately resistant, gray and tan, thin-bedded, ledgy, chert-bearing, marine dolomite and limestone (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); maximum thickness about 200 feet (60 m).

Kaibab Formation—Resistant, light- to dark-gray, medium-grained, thin- to thick-bedded, fossiliferous, marine limestone characterized by cliffs and ledges and by abundant dark-brown chert concretions and beds

(Earll, 1957; J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Corbett, 1984; Price, 1998); maximum thickness about 550 feet (170 m).

Pt **Toroweap Formation**—Generally resistant, light- to dark-gray, black, and tan, fine-grained, mostly thin-bedded, ledgy, locally cherty and fossiliferous, marine limestone and subordinate sandstone (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Corbett, 1984); mapped north of Minersville, where the maximum thickness is about 300 feet (100 m).

Pq **Queantoweap Sandstone** (Lower Permian)—Resistant, tan and pink, thin-bedded, ledgy, fine-grained sandstone and quartzite (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); mapped north and south of Minersville, where the maximum thickness is about 500 feet (150 m).

Pp **Pakoon Dolomite** (Lower Permian)—Alternating soft and resistant, light- to dark-gray and pink, ledgy and cliffy, medium-grained, thick-bedded, locally chert-bearing, marine dolomite and subordinate to minor sandstone (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Corbett, 1984; Price, 1998); mapped north and south of Minersville, where the thickness is about 800 feet (240 m).

PENNSYLVANIAN

ℙc **Callville Limestone** (Pennsylvanian)—Soft to moderately resistant, white and light-gray, fine-grained, thin- to medium-bedded, ledgy, locally fossiliferous, rarely cherty, marine limestone and minor gray, purple, and brown siltstone and fine-grained sandstone capped by an upper limestone cliff in the Bradshaw district (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978; Wardlaw, 1980; Corbett, 1984; Price, 1998); mapped north and south of Minersville, where the thickness is about 400 feet (120 m).

MISSISSIPPIAN

Mr **Redwall Limestone** (Lower Mississippian)—Resistant, light-gray to black, medium-grained, thick-bedded, highly fossiliferous, rarely cherty, spar-rich, marine limestone and, in the lower part, dolomite (J.E. Welsh and B.R. Wardlaw, unpublished data, 1978); forms massive cliffs; mapped north and south of Minersville, where the thickness is about 1,250 feet (380 m).

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REFERENCES

Anderson, J.J., 1965, Geology of the northern Markagunt Plateau, Utah: Austin, University of Texas, Ph.D. dissertation, 194 p., 2 plates, scale 1:62,500.

Anderson, J.J., 1971, Geology of the southwestern High Plateaus of Utah—Bear Valley Formation, an Oligocene-Miocene volcanic arenite: Geological Society of America Bulletin, v. 82, p. 1179–1205.

Anderson, J.J., 1993, The Markagunt Megabreccia—large Miocene gravity slides mantling the northern Markagunt Plateau, southwestern Utah: Utah Geological Survey Miscellaneous Publication 93-2, 37 p.

Anderson, J.J., and Rowley, P.D., 1975, Cenozoic stratigraphy of the southwestern High Plateaus of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 1–52.

Anderson, J.J., Rowley, P.D., Machette, M.N., Decatur, S.H., and Mehnert, H.H., 1990a, Geologic map of the Nevershine Hollow area, eastern Black Mountains, southern Tushar Mountains, and northern Markagunt Plateau, Beaver and Iron Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1999, scale 1:50,000.

Anderson, J.J., Rowley, P.D., Blackman, J.T., Mehnert, H.H., and Grant, T.C., 1990b, Geologic map of the Circleville Canyon area, southern Tushar Mountains and northern Markagunt Plateau, Beaver, Garfield, Iron, and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2000, scale 1:50,000.

Ball, J.L., Bailey, C., and Kunk, M.J., 2009, Volcanism on the Fish Lake Plateau, central Utah: Geological Society of America Abstracts with Programs, v. 41, no. 6, p. 17.

Bankey, V., Grauch, V.J.S., and Kucks, R.P., 1998, Utah aeromagnetic and gravity maps and data—a web site for distribution of data: Online, U.S. Geological Survey Open-File Report 98-761, https://pubs.usgs.gov/of/1998/ofr-98-0761/.

Best, M.G., Christiansen, E.H., and Blank, R.H., Jr., 1989a, Oligocene caldera complex and calc-alkaline tuffs and lavas of the Indian Peak volcanic field, Nevada and Utah: Geological Society of America Bulletin, v. 101, p. 1076–1090.

Best, M.G., Christiansen, E.H., Deino, A.L., Gromme, C.S., McKee, E.H., and Noble, D.C., 1989b, Excursion 3A—Eocene through Miocene volcanism in the Great Basin of the western United States: New Mexico Bureau of Mines and Mineral Resources Memoir 47, p. 91–133.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1035–1050.

Best, M.G., Scott, R.B., Rowley, P.D., Swadley, WC, Anderson, R.E., Gromme, C.S., Harding, A.E., Deino, A.L., Christiansen, E.H., Tingey, D.G., and Sullivan, K.R., 1993, Oligocene-Miocene caldera complexes, ash-flow sheets, and tectonism in the central and southeastern Great Basin, *in* Lahren, M.M., Texler, J.H., Jr., and Spinosa, C., editors, Crustal evolution of the Great Basin and Sierra Nevada: Field Trip Guide, Geological Society of America, Cordilleran and Rocky Mountain Sections Meeting, p. 285–311.

Biek, R.F., Eaton, J.G., Rowley, P.D., and Mattox, S.R., 2015b, Interim geologic map of the western Loa 30′ x 60′ quadrangle, Garfield, Piute, and Wayne Counties, Utah (year 2): Utah Geological Survey Open-File Report 648, 20 p., scale 1:62,500.

Biek, R.F., Hacker, D.B., and Rowley, P.D., 2014, New constraints on the extent, age, and emplacement history of the early Miocene Markagunt Megabreccia, southwest Utah—one of the World's largest subaerial gravity slides, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, CD, p. 565–598.

Biek, R.F., Rowley, P.D., Anderson, J.J., Maldonado, F., Moore, D.W., Hacker, D.B., Eaton, J.G., Hereford, R., Sable, E.G., Filkorn, H.F., and Matyjasik, B., 2015a, Geologic map of the Panguitch 30′ x 60′ quadrangle, Garfield, Iron, and Kane Counties, Utah: Utah Geological Survey Map 270DM, 162 p., CD, scale 1:65,000.

Blackman, J.T., 1985, Geology of a vent of the Mount Dutton Formation (Miocene), southwest Tushar Mountains, Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 80 p.

Blank, H.R., and Kucks, R.P., 1989, Preliminary aeromagnetic, gravity, and generalized geologic maps of the USGS Basin and Range–Colorado Plateau transition zone study area in southwestern Utah, southeastern Nevada, and northwestern Arizona (the "BARCO" project): U.S. Geological Survey Open-File Report 89-432, 27 p., scale 1:250,000.

Bowers, D., 1978, Potassium-argon age dating and petrology of the Mineral Mountains pluton, Utah: Salt Lake City, University of Utah, unpublished M.S. thesis, 76 p.

Budding, K.E., Cunningham, C.G., Zielinski, R.A., Steven, T.A., and Stern, C.R., 1987, Petrology and chemistry of the Joe Lott Tuff Member of the Mount Belknap Volcanics, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Professional Paper 1354, 47 p.

Callaghan, E., 1939, Volcanic sequence in the Marysvale region in southwest-central Utah: American Geophysical Union Transactions, 20th Annual Meeting, Washington, D.C., p. 438–452.

Callaghan, E., 1973, Mineral resources potential of Piute County, Utah and adjoining areas: Utah Geological and Mineralogical Survey Bulletin 102, 135 p.

Campbell, D.L., Steven, T.A., Cunningham, C.G., and Rowley, P.D., 1999, Aeromagnetic and gravity maps of the central Marysvale volcanic field, southwestern Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-2645-B, scale 1:100,000.

Christiansen, R.L., and Lipman, P.W., 1972, Cenozoic volcanism and plate tectonic evolution of the western United States—II. Late Cenozoic: Royal Society of London Philosophical Transactions (A), v. 271, p. 249–284.

Coleman, D.S., Bartley, J.M., Walker, J.D., Price, D.E., and Friedrich, A.M., 1997, Extensional faulting, footwall deformation and plutonism in the Mineral Mountains, southern Sevier Desert: Brigham Young University Geology Studies, v. 42, p. 203–233.

Coleman, D.S., Walker, J.D., Bartley, J.M., and Hodges, K.V., 2001, Thermochronologic evidence for footwall deformation during extensional core complex development, Mineral Mountains, Utah, *in* Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D., editors, The geologic transition, High Plateaus to Great Basin—a symposium and field guide (The Mackin Volume): Utah Geological Association and Pacific Section of the American Association of Petroleum Geologists, Utah Geological Association Publication 30, p. 155–168.

Corbett, M.D., 1984, Stratigraphy, structure, and skarn deposits within the Toroweap, Kaibab, and Moenkopi section, Lincoln mining district, southern Mineral Range, Beaver County, Utah: Golden, Colorado, Colorado School of Mines, unpublished M.S. thesis, 180 p.

Cornell, D., Butler, T., Holm, D., Hacker, D., and Spell, T., 2001, Stratigraphy and Ar/Ar ages of volcanic rocks of the Pinto quadrangle, Colorado Plateau transition zone, SW Utah [abs.], *in* Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D., editors, The geologic transition, High Plateaus to Great Basin—a symposium and field guide (The Mackin Volume): Utah Geological Association and Pacific Section of the American Association of Petroleum Geologists, Utah Geological Association Publication 30, p. 420–421.

Craddock, J.P., Geary, J., and Malone, D.H., 2012, Vertical injectites of detachment carbonate ultracataclasite at White Mountain, Heart Mountain detachment, Wyoming: Geology, v. 40, p. 463–466.

Craddock, J.P., Malone, D.H., Cook, A.L., Rieser, M.E., and Doyle, J.R., 2009, Dynamics of emplacement of the Heart Mountain allochthon at White Mountain—constraints from calcite twinning strains, anisotropy of magnetic susceptibility and thermodynamic calculations: Geological Society of America Bulletin, v. 121, no. 5/6, p. 919–938.

Cunningham, C.G., Ludwig, K.R., Naeser, C.W., Weiland, E.K., Mehnert, H.H., Steven, T.A., and Rasmussen, J.D., 1982, Geochronology of hydrothermal uranium deposits and associated igneous rocks in the eastern source area of the Mount Belknap Volcanics, Marysvale, Utah: Economic Geology, v. 77, no. 2, p. 453–463.

Cunningham, C.G., Rasmussen, J.D., Steven, T.A., Rye, R.O., Rowley, P.D., Romberger, S.B., and Selverstone, J., 1998a, Hydrothermal uranium deposits containing molybdenum and fluorite in the Marysvale volcanic field, west-central Utah: Mineralium Deposita, v. 33, p. 477–494.

Cunningham, C.G., Rowley, P.D., Steven, T.A., and Rye, R.O., 2007, Geologic evolution and mineral resources of the Marysvale volcanic field, west-central Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 143–162.

Cunningham, C.G., Rye, R.O., Steven, T.A., and Mehnert, H.H., 1984a, Origins and exploration significance of replacement and vein-type alunite deposits in the Marysvale volcanic field, west-central Utah: Economic Geology, v. 79, p. 50–71.

Cunningham, C.G., Rye, R.O., Rockwell, B.W., Kunk, M.J., and Councell, T.B., 2005, Supergene destruction of a hydrothermal replacement alunite deposit at Big Rock Candy Mountain, Utah—mineralogy, spectroscopic remote sensing, stable-isotope, and argon-age evidences: Chemical Geology, v. 215, p. 317–337.

Cunningham, C.G., and Steven, T.A., 1979, Mount Belknap and Red Hills calderas and associated rocks, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Bulletin 1468, 34 p.

Cunningham, C.G., Steven, T.A., Campbell, D.L., Naeser, C.W., Pitkin, J.A., and Duval, J.S., 1984b, Multiple episodes of igneous activity, mineralization, and alteration in the western Tushar Mountains, Marysvale volcanic field, west-central Utah, *in* Steven, T.A., editor, Igneous activity and related ore deposits in the western and southern Tushar Mountains, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Professional Paper 1299-A, 22 p.

Cunningham, C.G., Steven, T.A., Rowley, P.D., Glassgold, L.B., and Anderson, J.J., 1983, Geologic map of the Tushar Mountains and adjoining areas, Marysvale volcanic field, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1430-A, scale 1:50,000.

Cunningham, C.G., Steven, T.A., Rowley, P.D., Naeser, C.W., Mehnert, H.H., Hedge, C.E., and Ludwig, K.R., 1994, Evolution of volcanic rocks and associated ore deposits in the Marysvale volcanic field, Utah: Economic Geology, v. 89, p. 2003–2005.

Cunningham, C.G., Unruh, D.M., Steven, T.A., Rowley, P.D., Naeser, C.W., Mehnert, H.H., Hedge, C.E., and Ludwig, K.R., 1998b, Geochemistry of volcanic rocks in the Marysvale volcanic field, west-central Utah, *in* Friedman, J.D., and Huffman, A.C., Jr., coordinators, Laccolith complexes of southeastern Utah—time of emplacement and tectonic setting—workshop proceedings: U.S. Geological Survey Bulletin 2158, p. 223–232.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558–560.

Damon, P.E., 1969, Correlation and chronology of ore deposits and volcanic rocks: Tucson, University of Arizona, Geochronology Laboratory, U.S. Atomic Energy Commission Contract AT(11-1)-689, Annual Progress Report COO-689-120, 90 p.

Earll, F.N., 1957, Geology of the central Mineral Range, Beaver County, Utah: Salt Lake City, Utah, University of Utah, unpublished Ph.D. dissertation, 112 p.

Evans, S.H., Jr., and Steven, T.A., 1982, Rhyolites in the Gillies Hill–Woodtick Hill area, Beaver County, Utah: Geological Society of America Bulletin, v. 93, p. 1131–1141.

Fleck, R.J., Anderson, J.J., and Rowley, P.D., 1975, Chronology of mid-Tertiary volcanism in High Plateaus region of Utah, *in* Anderson, J.J., Rowley, P.D., Fleck, R.J., and Nairn, A.E.M., editors, Cenozoic geology of southwestern High Plateaus of Utah: Geological Society of America Special Paper 160, p. 53–62.

Fryman, M.D., 1987, The Isom Formation of the Markagunt Plateau in southwestern Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 86 p.

Grant, T.C., and Anderson, J.J., 1979, Geology of the Spry intrusion, Garfield County, Utah: Utah Geology, v. 6, p. 5–24.

Hacker, D.B., Biek, R.F., and Rowley, P.D., 2014, Catastrophic emplacement of the gigantic Markagunt gravity slide, southwest Utah (USA)—implications for hazards associated with sector collapse of volcanic fields: Geology, v. 42, no. 11, p. 943–946.

Hacker, D.B., Biek, R.F., and Rowley, P.D., 2015, Earth's largest terrestrial landslide (the Markagunt gravity slide of southwest Utah)—insights from the catastrophic collapse of a volcanic field: AGU abstracts, https://agu.confex.com/agu/fm15/meetingapp.cgi/Paper/76934.

Hintze, L.F., Davis, F.D., Rowley, P.D., Cunningham, C.G., Steven, T.A., and Willis, G.C., 2003, Geologic map of the Richfield 30′ x 60′ quadrangle, southeast Millard County and parts of Beaver, Piute, and Sevier Counties, Utah: Utah Geological Survey Map 195, scale 1:100,000.

Kerr, P.F., Brophy, G.P., Dahl, H.M., Green, J., and Woolard, L.E., 1957, Marysvale, Utah, uranium area—geology, volcanic relations, and hydrothermal alteration: Geological Society of America Special Paper 64, 212 p.

Kowallis, B.J., and Best, M.G., 1990, Fission track ages from volcanic rocks in southwestern Utah and southeastern Nevada: Isochron/West, no. 55, p. 24–27.

Lanigan, J.C., Jr., and Anderson, J.J., 1987, Geology of the lower canyon of Beaver River, southwestern Tushar Mountains, Utah, *in* Kopp, R.S., and Cohenour, R.E., editors, Cenozoic geology of western Utah: Utah Geological Association Publication 16, p. 417–428.

Lipman, P.W., Prostka, H.J., and Christiansen, R.L., 1972, Cenozoic volcanism and evolution of the western United States—I. Early and middle Cenozoic: Royal Society of London, Philosophical Transactions (A), v. 271, p. 217–248.

Lipman, P.W., Rowley, P.D., Mehnert, H.H., Evans, S.H., Jr., Nash, W.P., and Brown, F.H., 1978, Pleistocene rhyolite of the Mineral Mountains, Utah—geothermal and archeological significance, *with sections on* Fission-track dating, by Izett, G.A., and Naeser, C.W., *and on* Obsidian-hydration dating, by Irving Friedman: U.S. Geological Survey Journal of Research, v. 6, no. 1, p. 133–147.

Machette, M.N., 1985, Late Cenozoic geology of the Beaver basin, southwestern Utah: Brigham Young University Studies in Geology, v. 32, pt. 1, p. 19–37.

Machette, M.N., Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984, Geologic map of the Beaver quadrangle, Beaver and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1520, scale 1:50,000.

Mackin, J.H., 1960, Structural significance of Tertiary volcanic rocks in southwestern Utah: American Journal of Science, v. 258, no. 2, p. 81–131.

Malone, D.H., and Craddock, J.P., 2008, Recent contributions to the understanding of the Heart Mountain detachment, Wyoming: Northwest Geology, v. 37, p. 21–40.

Malone, D.H., Craddock, J.P., and Mathesin, M.G., 2014, Origin of allochthonous volcanic rocks at Squaw Peaks, Wyoming—a distal remnant of the Heart Mountain slide?: Mountain Geologist, v. 51, p. 321–336.

Mehnert, H.H., Rowley, P.D., and Lipman, P.W., 1978, K-Ar ages and geothermal implications of young rhyolites in west-central Utah: Isochron/West, no. 21, p. 3–7.

Price, D.E., 1998, Timing, magnitude, and three-dimensional structure of detachment-related extension, Mineral Mountains, Utah: Salt Lake City, Utah, University of Utah, unpublished M.S. thesis, 67 p., scale 1:24,000.

Rowley, P.D., 1968, Geology of the southern Sevier Plateau, Utah: Austin, University of Texas, unpublished Ph.D. dissertation, 385 p., scale 1:62,500.

Rowley, P.D., 1978, Geologic map of the Thermo 15-minute quadrangle, Beaver and Iron Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1493, scale 1:62,500.

Rowley, P.D., 1998, Cenozoic transverse zones and igneous belts in the Great Basin, western United States—their tectonic and economic implications, *in* Faulds, J.E., and Stewart, J.H., editors, Accommodation zones and transfer zones—the regional segmentation of the Basin and Range Province: Geological Society of America Special Paper 323, p. 195–228.

Rowley, P.D., Biek, R.F., Sable, E.G., Boswell, J.T., Vice, G.S., Hatfield, S.C., Maxwell, D.J., and Anderson, J.J., 2013, Geologic map of the Brian Head quadrangle, Iron County, Utah: Utah Geological Survey Map 263DM, CD, 38 p., scale 1:24,000.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1988a, Geologic map of the Antelope Range quadrangle, Sevier and Piute Counties, Utah: Utah Geological and Mineral Survey Map 106, scale 1:24,000.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1988b, Geologic map of the Marysvale quadrangle, Piute County, Utah: Utah Geological and Mineral Survey Map 105, scale 1:24,000.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Mehnert, H.H., and Naeser, C.W., 1998, Cenozoic igneous and tectonic setting of the Marysvale volcanic field, and its relation to other igneous centers in Utah and Nevada, in Friedman, J.D., and Huffman, A.C., Jr., coordinators, Laccolith complexes of southeastern Utah—time of emplacement and tectonic setting—workshop proceedings: U.S. Geological Survey Bulletin 2158, p. 167–202.

Rowley, P.D., Cunningham, C.G., Steven, T.A., Workman, J.B., Anderson, J.J., and Theissen, K.M., 2002, Geologic map of the central Marysvale volcanic field, southwestern Utah: U.S. Geological Survey Geologic Investigations Series Map I-2645-A, scale 1:100,000.

Rowley, P.D., and Dixon, G.L., 2001, The Cenozoic evolution of the Great Basin area, U.S.A.—new interpretations based on regional geologic mapping, *in* Erskine, M.C., Faulds, J.E., Bartley, J.M., and Rowley, P.D., editors, The geologic transition, High Plateaus to Great Basin—a symposium and field guide (The Mackin Volume): Utah Geological Association and Pacific Section of the American Association of Petroleum Geologists, Utah Geological Association Publication 30, p. 169–188.

Rowley, P.D., Lipman, P.W., Mehnert, H.H., Lindsey, D.A., and Anderson, J.J., 1978, Blue Ribbon lineament, an east-trending structural zone within the Pioche mineral belt of southwestern Utah and eastern Nevada: U.S. Geological Survey Journal of Research, v. 6, no. 2, p. 175–192.

Rowley, P.D., Mehnert, H.H., Naeser, C.W., Snee, L.W., Cunningham, C.G., Steven, T.A., Anderson, J.J., Sable, E.G., and Anderson, R.E., 1994a, Isotopic ages and stratigraphy of Cenozoic rocks of the Marysvale volcanic field and adjacent areas, west-central Utah: U.S. Geological Survey Bulletin 2071, 35 p.

Rowley, P.D., Nealey, L.D., Unruh, D.M., Snee, L.W., Mehnert, H.H., Anderson, R.E., and Gromme, C.S., 1995, Stratigraphy of Miocene ash-flow tuffs in and near the Caliente caldera complex, southeastern Nevada and southwestern Utah, *in* Scott, R.B., and Swadley, WC, editors, Geologic studies in the Basin and Range—Colorado Plateau transition in southeastern Nevada, southwestern Utah, and northwestern Arizona, 1992: U.S. Geological Survey Bulletin 2056, p. 43–88.

Rowley, P.D., Norlin, K., Maxwell, J.A., and Maxwell, D.J., 2014, The Minersville gravity slide and metallic mineral potential at Black Mountain, northern Black Mountains, Beaver County, Utah, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, CD, p. 599–616; includes 1:6,000-scale geologic map as Plate 1.

Rowley, P.D., Shroba, R.R., Simonds, F.W., Burke, K.J., Axen, G.J., and Olmore, S.D., 1994b, Geologic map of the Chief Mountain quadrangle, Lincoln County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-1731, scale 1:24,000.

Rowley, P.D., Snee, L.W., Mehnert, H.H., Anderson, R.E., Axen, G.J., Burke, K.J., Simonds, F.W., Shroba, R.R., and Olmore, S.D., 1992, Structural setting of the Chief Mining District, eastern Chief Range, Lincoln County, Nevada, *in* Thorman, C.H., editor, Application of structural geology to mineral and energy resources of the central and western United States: U.S. Geological Survey Bulletin 2012, p. H1–H17.

Rowley, P.D., Steven, T.A., Anderson, J.J., and Cunningham, C.G., 1979, Cenozoic stratigraphic and structural framework of southwestern Utah: U.S. Geological Survey Professional Paper 1149, 22 p.

Rowley, P.D., Steven, T.A., and Mehnert, H.H., 1981, Origin and structural implications of upper Miocene rhyolites in Kingston Canyon, Piute County, Utah: Geological Society of America Bulletin, Pt. I, v. 92, p. 590–602.

Rowley, P.D., Vice, G.S, McDonald, R.E., Anderson, J.J., Machette, M.N., Maxwell, D.J., Ekren, E.B., Cunningham, C.G., Steven, T.A., and Wardlaw, B.R., 2005, Interim geologic map of the Beaver 30′ x 60′ quadrangle, Beaver, Piute, Iron, and Garfield Counties, Utah: Utah Geological Survey Open-File Report 454, 32 p., scale 1:100,000.

Rowley, P.D., Williams, P.L., and Kaplan, A.M., 1986a, Geologic map of the Greenwich quadrangle, Piute County, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1589, scale 1:24,000.

Rowley, P.D., Williams, P.L., and Kaplan, A.M., 1986b, Geologic map of the Koosharem quadrangle, Sevier and Piute Counties, Utah: U.S. Geological Survey Geologic Quadrangle Map GQ-1590, scale 1:24,000.

Sable, E.G., and Maldonado, F., 1997, The Brian Head Formation (revised) and selected Tertiary sedimentary rock units, Markagunt Plateau and adjacent areas, southwestern Utah, *in* Maldonado, F., and Nealey, L.D., editors, Geologic studies in the Basin and Range–Colorado Plateau transition zone in southeastern Nevada, southwestern Utah, and northwestern Arizona, 1995: U.S. Geological Survey Bulletin 2153, p. 7–26.

Sigmund, J.M., 1979, Geology of a Miocene rhyodacite lava flow, southern Tushar Mountains, Utah: Kent, Ohio, Kent State University, M.S. thesis, 35 p.

Steiger, R.H., and Jager, E., 1977, Subcommission on Geochronology—convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, p. 359–362.

Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1984a, Geologic history and uranium potential of the Big John caldera, southern Tushar Mountains, Utah, *in* Steven, T.A., editor, Igneous activity and related ore deposits in the western and southern Tushar Mountains, Marysvale volcanic field, west-central Utah: U.S. Geological Survey Professional Paper 1299-B, 33 p.

Steven, T.A., Cunningham, C.G., and Machette, M.N., 1981, Integrated uranium systems in the Marysvale volcanic field, west-central Utah, *in* Goodell, P.C., and Waters, A.C., editors, Uranium in volcanic and volcaniclastic rocks: American Association of Petroleum Geologists Studies in Geology, no. 13, p. 111–122.

Steven, T.A., Cunningham, C.G., Naeser, C.W., and Mehnert, H.H., 1979, Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S. Geological Survey Bulletin 1469, 40 p.

Steven, T.A., and Morris, H.T., 1987, Summary mineral resource appraisal of the Richfield 1° x 2° quadrangle, west-central Utah: U.S. Geological Survey Circular 916, 24 p.

Steven, T.A., Morris, H.T., and Rowley, P.D., 1990, Geologic map of the Richfield 1° x 2° quadrangle, west-central Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1901, scale 1:250,000.

Steven, T.A., Rowley, P.D., and Cunningham, C.G., 1984b, Calderas of the Marysvale volcanic field, west-central Utah: Journal of Geophysical Research, v. 89, no. B10, p. 8751–8764.

Wardlaw, B.R., 1980, The Pennsylvanian Callville Limestone in Beaver County, southwestern Utah, *in* Fouch, T.D., and Magatham, E.R., editors, Paleozoic paleogeography of west-central United States: S.E.P.M. West-Central United States Paleogeography Symposium, Rocky Mountain Section, Denver, Colorado, p. 175–179.

Wickstrom, L.H., 1982, Geology of a Miocene felsic tuff and overlying basalts, southwestern Tushar Mountains, Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 61 p.

Williams, P.L., 1967, Stratigraphy and petrography of the Quichapa Group, southwestern Utah and southeastern Nevada: Seattle, University of Washington, unpublished Ph.D. dissertation, 182 p.

Williams, P.L., and Hackman, R.J., 1971, Geology, structure, and uranium deposits of the Salina quadrangle, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-591, scale 1:250,000.

Yannacci, D.S., 1986, The Buckskin Breccia—A block and ash-flow tuff of Oligocene age in the southwestern High Plateaus of Utah: Kent, Ohio, Kent State University, unpublished M.S. thesis, 107 p.

SOURCE LIST FOR GEOLOGIC MAPPING

(Numbers correspond to those on index map)

1. Anderson, J.J., 1965, Geology of northern Markagunt Plateau, Utah: Austin, University of Texas, unpublished Ph.D. dissertation, 194 p., scale 1:62,500.

2. Anderson, J.J., Rowley, P.D., Machette, M.N., Decatur, S.H., and Mehnert, H.H., 1990a, Geologic map of the Nevershine Hollow area, eastern Black Mountains, southern Tushar Mountains, and northern Markagunt Plateau, Beaver and Iron Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1999, scale 1:50,000.

3. Rowley, P.D., Vice, G.S., and McDonald, R.E., 2003–2004, unpublished mapping of bedrock and surficial geology, scale 1:100,000.

4. Rowley, P.D., Wardlaw, B.R., and Machette, M.N., 1970–1980, unpublished mapping of bedrock and surficial geology of the Minersville 15′ quadrangle, scale 1:62,500.

MAP SYMBOLS

Contact

High-angle normal fault, dashed where approximately located; dotted where concealed; bar and ball on downthrown side

Transverse fault (Rowley, 1998), striking generally east; may be a normal fault, a strike-slip fault, or an oblique-slip fault; dashed where approximately located, dotted where concealed; bar and ball on downthrown side, where known; arrows show relative strike-slip movement, where known

Gravity-slide faults. Main or subsidiary breakaway fault (with normal-slip motion and within the gravity slide); most faults are high-angle but some represent failure along incompetent (weak) beds and are low-angle; symbol is the same for the breakaway faults of the Markagunt, Minersville, and Showalter Mountain gravity slides, but they are distinguished by the name of the slide "Markagunt," "Minersville," and "Showalter Mountain" adjacent to most slide symbols (except where the identity of some slide symbols are obvious); dashed where approximately located, dotted where concealed; teeth on downthrown side or upper plate

Volcanic vent

Strike and dip angle of inclined bedding

CORRELATION OF MAP UNITS